High Temperature Stress Relaxation Properties of Ferritic Pressure Vessel Steel

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by

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ABSTRACT

Components of fossil fuelled power generation plant operate under conditions of high pressure and high temperature. Low alloy, ferritic steels are commonly used in the manufacture of these components as they provide the essential attributes of economy, creep resistance and relative ease of manufacture. Creep is the dominant metallurgical damage process leading to the eventual redundancy of high temperature plant. However, during periods such as start-ups, shutdowns and cyclic operation, the effects of load and thermal transients may give rise to other damage mechanisms such as stress relaxation (SR).

Published studies on the SR behaviour of steels have mainly concentrated on alloys used as high temperature fasteners. A large amount of reference SR data is available for steels such as 1Cr-0.5Mo and 12Cr, which are commonly employed in bolting applications on high pressure steam turbines. However, very limited SR data is currently available for ferritic pressure vessel steels or specifically, 2.25Cr-1Mo, a steel used extensively in pressure components within the power generation industry.

R5 is an assessment procedure for the high temperature response of structures. It was originally developed by the former Central Electricity Generating Board (CEGB) in the UK and is widely used by engineers engaged in life assessment studies of high temperature pressure plant. R5 requires the input of SR data to evaluate the contribution of SR to the total creep damage in remaining life estimation. Previously however, this data has been unavailable.

An objective of the research undertaken in this study was to address the situation by characterising the SR properties of virgin, normalised and tempered, 2.25Cr-1Mo steel over a range of relevant temperatures. Additional objectives, of the project, were aimed at developing a methodology for obtaining SR data from service-aged material and studying the interaction of SR and creep by a combination of test techniques.

A broad SR test program was undertaken on standard sized SR samples, at temperatures of 600, 570, 550, 500 and 380°C, to obtain a comprehensive set of SR test data for

virgin, normalised and tempered, 2.25Cr-1Mo steel. The results emanating from this section of the research will be of great benefit in future life assessment studies of components manufactured from this material.

A new test system was developed to enable SR data to be obtained from service-aged steel by testing miniature samples extracted from in-service components. SR tests conducted at 550°C on miniature samples were compared with standard sized sample tests at the same temperature. Comparison of test data from miniature and standard sized samples showed reasonably good agreement.

The effect of prior SR loading cycles on creep life was evaluated at 550°C and stresses of 100 and 140 MPa. A significant reduction in creep life was observed as a result of the prior SR loadings.

Certificate of Authorship / Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Samuel D. Humphries

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Symbols

E	Young's Modulus
N	cycle number
T	Temperature
t	time
t_f	final time (SR test)
t_0	zero time at start of SR test
t_r	time to rupture
$t_{r(\mathrm{ime})}$	time to rupture (Inst Mech Eng [5])
t_{SR}	total SR time
$t_{2.5\%\varepsilon}$	time to reach 2.5% strain (test data)
$t_{2.5\%\varepsilon(\mathrm{ime})}$	time to reach 2.5% strain (Inst Mech Eng [5])
ε_e	elastic strain
ε_i	initial (control) strain SR test
ε_p	plastic strain
ε_T	total strain
σ	stress (instantaneous stress at time t)
σ_o	initial stress
σ_f	final stress at time t
σ_r	relaxed stress (σ_o - σ)
σ_y	yield stress

Abbreviations

EGL	effective gauge length
GL	gauge length
SR	stress relaxation
LCF	low cycle fatigue